Senior Thesis

A Ground Water Report on the Fernald, Ohio Contamination in the Miami Valley Aquifer

by
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1996

Submitted as partial fulfillment of
the requirements for the degree of
Bachelor of Science in the Geology
Department at The Ohio State University,
Spring Quarter, 1996

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INTRODUCTION

Fernald, Ohio is located in a rural area of Hamilton and Butler counties. Fernald is approximately 17 miles northwest of Cincinnati, Ohio (fig. 1). The study site is the Fernald Federal Facility for the Department of Energy which was contaminated by a variety of defense activities. Residences and villages surround the site within a 5 mile radius. These villages include Fernald, New Baltimore, Ross, New Haven, and Shandon. The land use in the area around the Fernald site include agriculture and cattle farming.

The Federal Facility was used for the production of pure uranium materials for the Department of Energy. The manufacturing of uranium products was produced by different chemical and metallurgical processes. The raw product or impure starting materials was dissolved in nitric acid. The nitric acid and uranium went through a solvent extraction to produce uranyl nitrate, a purified uranium. The uranyl nitrate was converted to a uranium trioxide powder (UO_3) by heating and evaporating the nitrate solution. The uranium trioxide powder was made into a uranium dioxide by a chemical reaction hydrogen. The uranium dioxide was turned into uranium tetrafluoride (UF_4) by reacting the uranium dioxide with anhydrous hydrogen fluoride. Uranium metal was made by reacting the uranium tetrafluoride and magnesium metal. This metal was remelted with scrap uranium metal to produce a purer uranium ignot. There were different metal working processes done at this facility along with the long term storage and thorium repository.

A variety of waste disposal activities have lead to wide spread contamination of this site. Solid and slurried wastes were disposed of on the on property storage areas before 1984. The storage areas are comprised of six low level radioactive waste storage pits, two concrete silos containing radium bearing materials produced during the refining process (K-65 residues), one silo containing metal oxides, one empty silo, two lime sludge ponds, and one solid waste landfill.

PURPOSE OF THIS STUDY

The purpose of this study is to describe the regional and local geology in terms that relate it to the hydrology of the Fernald site. The geology of the area will show the tendencies of the Great Miami Aquifer, the important role of the glacial overburden, and the importance of the valley walls. The knowledge geology of the site will enable the interpretation of the hydrologic setting. The hydrologic setting is comprised of the Great Miami Aquifer, perched water tables, and surface water. The contamination of the Fernald site is due to the interaction of the surface water and the aquifer below the land surface.

DESCRIPTION OF PHYSICAL SETTING

Southwestern Ohio is underlain by Paleozoic bedrock and glacial deposits. The bedrock is thinly bedded shales and fossiliferous limestones which are nearly horizontal. These shales and limestones are Middle to Late Ordovician in age. The Fernald site sits close to the Cincinnati Arch which is an anticline with its axis running predominantly north and south. The site itself is located within a deep bedrock valley.

The glacial deposits in Southwestern Ohio are related to three main glacial cycles in Pliestocene age. The Fernald site lies on the border of the glaciated lowlands and unglaciated uplands. The glaciation events were transgressional and regressional events of the continental ice sheets which allowed the bedrock to be eroded and depositionaly filled respectively. With the weight of the continental ice sheets, the crust of the earth sinks down or depresses causing the sea level to drop with most of the earth's water tied up in the ice. When the ice melts, the crust rebounds or lifts up allowing the sea level to rise. The rise in sea level allows the rivers and streams to cut deep into the bedrock valleys. The glacial outwash and till fill the bedrock valleys that were carved out by the glacial event. The outwash is carried downstream by the rivers and streams which was rocks and sediments broken up by the glacier. The top of the fill is comprised of a clay rich overburden from the last glacial event. The erosion on the Great Miami River has removed the clay rich overburden and is in contact with the Great Miami Aquifer. The aquifer is buried below the overburden in the glacial outfwash. Paddy's Run is also in contact with the glacial outwash which remains dry except during rainfall.

The local geology of the Fernald site reflects the regional effects of glaciation. The Fernald site sits on a U shaped buried valley that varies in width from 1.5 to 2 miles (fig. 2). The valley has a relatively flat bottom and steep walls. The valley itself is partially filled by outwash of sands and gravels. There are also interbedded glacial tills in the outwash which are comprised of poorly sorted pebbles, cobbles, and boulders in a predominant clay matrix.

The outwash unit comprises the Great Miami Aquifer which extends northward to Dayton. Locally, these deposits are well sorted sands and gravels with minor amounts of clays and silts. At Fernald, there is an interbedded layer of clay in the course grained sediments which underlie most of the Fernald site (fig. 2). This interbed divides the aquifer into upper and lower halves. The clay interbed is 100 to 125 feet below the land surface. The clay interbed acts as an aquitard because of the highly homogenous impermeable clay that varies in thickness from 1 to 20 feet. The clay layer pinches out to the south and east, continues to an unknown distance to the west, and grades into lacustrine, glacial fluvial, and till deposits to the north.

The upper portion of the glacial overburden is comprised of loess or wind blown sediments, lacustrine deposits or well sorted sands and clays, till, and glacial fluvial deposits. These units overlie the Great Miami Aquifer. The overburden varies throughout the study area. At the Fernald site, the upper drift units range from 5 to 50 feet in thickness but is mostly between 20 to 30 feet thick. The unit extends past the site north in the and west sides but it disappears in the south and east where the Miami River has eroded it away.

The hydrologic setting of the Fernald site can be described in terms of several important features including: the Great Miami Aquifer and perched glacial overburden groundwater, the local potentiometric surface and measured direction of groundwater flow, and interactions of ground water with Paddy's Run and the Miami River.

The Great Miami Aquifer is an unconfined aquifer which can be described in terms of transmisivity and specific yield. Transmisivity is the ability of the water to move through the material of the aquifer. The higher the transmisivity the more water can be transmitted by the aquifer. Specific yield is the ability of the aquifer to store water. The specific yield is the measure of the storage of water when the hydraulic head is decreased, this is effected by the porosity and the grain size of the aquifer. The coarser grained sediments have a higher specific yield while the smaller grained sediments is less but the water retained during extraction of the water is smaller and greater, respectively.

There are two types of hydrologic environments in the Fernald site which are referred to locally as type I and III (fig. 3). Type I is a well sorted sand and gravel aquifer, containing scattered clay lenses or fine grained material, which has the potential of infiltration from stream recharge. This type is found along the flood plain of the Great Miami River east and south of the site. Paddy's Run Valley is also this type located in the west and south. The aquifer is 150 to 200 feet thick and has a bedrock bottom. The aquifer are outcrop at the surface allowing for easy recharge. The transmisivity ranges from 40,000 to 67,000 square feet per day and a specific yield of about 0.2. Type III is a well sorted sand and gravel aquifer with a clay lense interbed and a clay glacial overburden that lies directly underneath the site. The clay interbed is 10 to 20 feet thick and is about 140 feet below the surface. This unit, as stated previously divides the aquifer into upper and lower halves. The lower aquifer is a leaky confined or semiconfined aquifer. The estimated coefficent of storage for the lower sand and gravel aquifer was estimated at 0.001 and transmisivity range of 4,700 to 40,000 square feet per day.

The glacial overburden groundwater system is locally perched groundwater in the overburden. This uppermost layer restricts the recharge of the aquifer (type III) and acts as an aquitard in most places, where it contains a densely fine grained till and laclustrine deposits of silt and clay. There are small scale fluvial and sand deposits interbeded in the till that have a relatively high hydraulic conductivity. The hydraulic conductivities of these units range from 0.008 to 0.85 feet per day. The depth to the perched groundwater at the Fernald site ranges from 1 to 15 feet in the overburden. The water table can vary as much as 10 feet due to the seasons. The maximum rise is observed in spring and the minimum in the late fall. The perched groundwater at the Fernald site flows in the direction of Paddy's Run and the storm sewer ditch. The movement of groundwater is likely to be independent of the deeper system because the perched water tables are not connected.

The groundwater flow pattern is controlled by the groundwater moving from higher to lower hydraulic heads. The groundwater has three main sources in the aquifer around the Fernald site. The first comes from the area around Ross and flows in a south to southwestern direction. The second comes from the Shandon area and flows south to southeast. The third comes from the New Baltimore area and flows east. These flows join around the Fernald site and follow the pattern of the Great Miami River in the sublevel of the aquifer. The hydraulic gradient fluctuates during the late fall and early spring. The groundwater maps were constructed using the hydraulic heads in the wells of the area in August 1982 (fig. 4), April 1988 (fig. 5), and May 1988 (fig. 6).

The following conclusions can be reached from the ground water maps. The production wells east of the Fernald site at the "Big Bend" meander in the river causes a cone of depression creating the flow to be in a more northwestern to southeastern direction on the Fernald site location. Paddy's Run affects the flow in the western part of the site by the wet and dry seasons. During the dry season the flow is in a southeastern direction. The rainy season causes mounding and strong southward gradients due to the recharge of the aquifer. The north part of the site has a local reversal due to the mounds. The monthly groundwater monitoring shows the transient groundwater conditions due to seasonal differences in recharge (fig. 7).

The surface water and ground water interactions with the Great Miami River and Paddy's Run are caused by the erosion of the low permeability overburden that provides direct contact with the underlying aquifer unit. This contact allows the direct exchange of water between the surface water and the groundwater. This is an important relationship to the increased pumping of the aquifer and the contamination transport in the Fernald site area.

The Great Miami River lies partially below the level in the water table so that part of the water in the river comes from groundwater and part from surface water. The natural interaction flow in from the aquifer to the river but due to the increased pumping of the aquifer, there is sufficient recharge by infiltration in the areas that pump the aquifer close to the river. This is produced by the change in local hydraulic gradient causing the recharge of the aquifer from the river. The rate of the infiltration is affected by the seasons and location on the stream. The river stage, hydraulic gradient, streambed features, and water temperature influence the infiltration rate.

The interaction of Paddy's Run and the Great Miami Aquifer produce different effects in the groundwater flow and discharge of the aquifer. The glacial overburden has been eroded by the stream to the top of the aquifer almost to the location of the silos, allowing this to be directly connected to the aquifer. South of the site, the water table is above or at the same as the elevation of the streambed. Here, the stream is recharged by the aquifer. The streambed is above the elevation of the aquifer in the vicinity of the site which allows recharge to the aquifer. The stream in this area remains dry except in times of runoff from rain or snow. There is hardly any recharge to the aquifer where the streambed is underlain by the clay overburden in the site north of the silos. The peak in Paddy's Run hydrograph is followed by a peak in the groundwater hydrograph a short time later. These peaks shows a direct hydrologic connection between the aquifer and Paddy's Run (fig. 8). When there is an increase in recharge due to excessive rain or snow, the groundwater flow creates mounds which affects the direction of the groundwater flow.

The flow system does not include the glacial overburden which covers most of the area of study. The overburden contains localized flow systems and gives little recharge to the aquifer by water percolating down. The effects are taken into account by using a lower value of recharge in the areas where the low permability layers are present. The no flow boundaries include the bedrock bottom floor, and valley walls. The constant head boundary conditions are represented by the Great Miami Aquifer boundaries at the exterior of the model grid . The model that was generated for the site is modeled by using the SWIFT III program (fig. 9).

GROUND-WATER CONTAMINATION-SOUTH PLUME

The contamination of uranium in the groundwater is located south of the Fernald site (fig. 10). The analytical solute transport model was used to determine the range of values for dispersion and retardation in the Great Miami Aquifer. The best calibration of the trials came from having a retardation factor of 12, a distribution coefficient of 0.022 (ft^3/lb), longitudinal dispersivity of 100 (ft). The contoured field data has sharper plume boundaries than the model is due to the model's ability to interpolate into other regions. The sensitivity of the model depends on the amount and location of source loading.

The south plume area of the Fernald site has a groundwater velocity of 1.33 ft/day. The plume area has a hydraulic conductivity of 400 ft/day. The longitudinal dispersivity has a value of 100. The pumping rate Q for the average of the wells is 112.5 gal/min. A porosity of 0.25. The distribution coefficient of the uranium is 0.022 cubic feet/lb. The initial estimate was 4749 lb. of uranium in the aquifer done by the IT corp. The half life of uranium-238, -235, -234 isotopes are 4.9×10^{9}, 7.04×10^{8}, 2.47×10^{5} years respectively.

CALCULATIONS

R_f = retardation factor (12)

v_w = linear velocity of water (0.406 m/day)

v_c = linear velocity of contaminant

n = porosity (0.25)

p_s = density (2.66 g/cc)

K_d = distribution coefficient

$R_f = v_w / v_c$

$K_d = [(R_f - 1)(1 - n)/ n\, p_s]$

$v_c = 0.033$ m/day

$K_d = 12.41$ cc/gram

Q = pumping rate 85.3 m^3/day (225 gal/min)

w = weight of contaminant 2.16 x 10e3 kg (4749 lb)

t = time

x = distance of farthest point of plume from well 1372 m. (both plumes)

$t = x / v_c$

t = 114 years for the contaminant to reach the wells

This long period of time for the pump and treat system is due to the retardation factor of the contaminant. This is the best estimate that can be given for the furthest point of the plume to reach the well and be treated. If this was just at the velocity of the water then it would only take 9.25 years.

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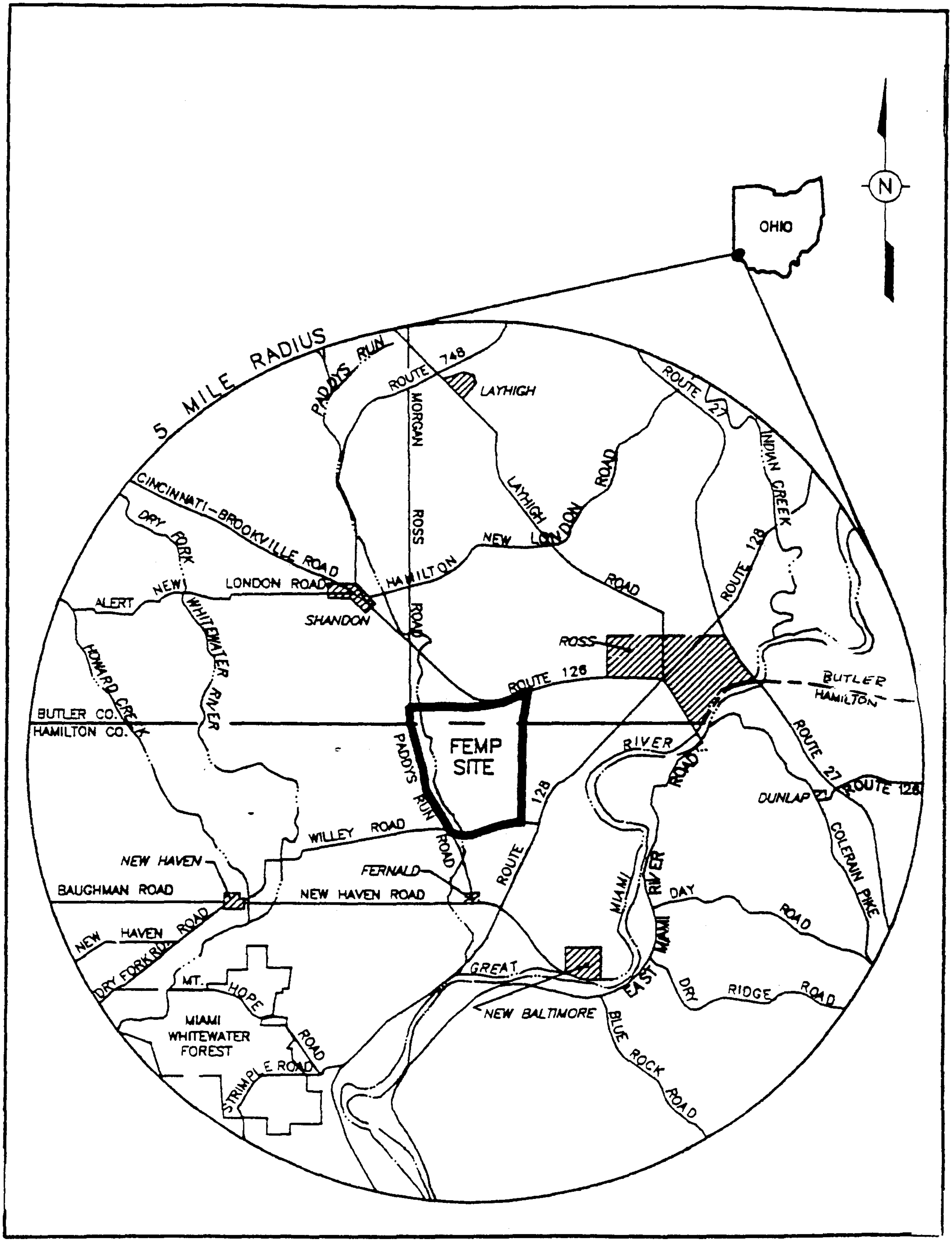
IT Corporation, 1993, "Groundwater Modeling Report Summary of Model Development, Fernald Environmental Management Project Fernald, Ohio", prepared for U.S. Department of Energy, Oak Ridge Operations, Oak Ridge, Tennessee

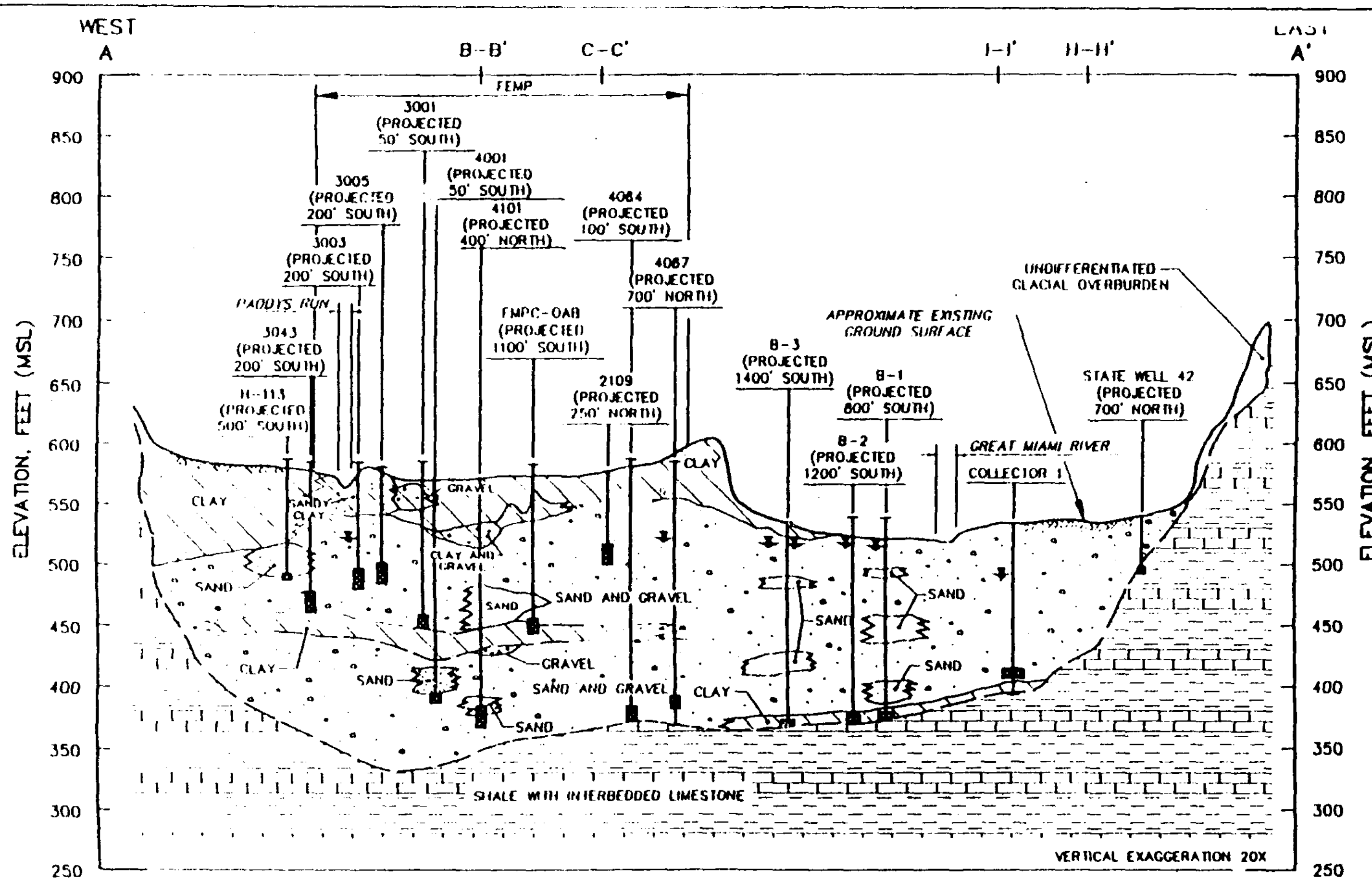


(GW) (PGH)

406

FEMP FIVE-MILE RADIUS MAP

Fig. 1



CROSS SECTION A–A'

(LOOKING NORTH)

THE BORING LOGS AND RELATED INFORMATION DEPICT SUBSURFACE CONDITIONS ONLY AT THE SPECIFIC LOCATIONS AND DATES INDICATED. SOIL CONDITIONS AND WATER LEVELS AT OTHER LOCATIONS MAY DIFFER FROM CONDITIONS OCCURRING AT THESE BORING LOCATIONS. ALSO THE PASSAGE OF TIME MAY RESULT IN A CHANGE IN THE CONDITIONS AT THESE BORING LOCATIONS.

THE DEPTH AND THICKNESS OF THE SUBSURFACE STRATA INDICATED ON THE SECTIONS WERE GENERALIZED FROM AND INTERPOLATED BETWEEN THE TEST BORINGS. INFORMATION ON ACTUAL SUBSURFACE CONDITIONS EXISTS ONLY AT THE LOCATION OF THE TEST BORINGS AND IT IS POSSIBLE THAT SUBSURFACE CONDITIONS BETWEEN THE TEST BORINGS MAY VARY FROM THOSE INDICATED.

VERTICAL SCALE

0 100 200 FEET

HORIZONTAL SCALE

0 2000 4000 FEET

LEGEND:

WATER LEVELS (MEASURED 3/27/88 THROUGH 4/11/88)

INFERRED CONTACT

OPEN OR SCREENED INTERVAL

NOTE:

FOR LOCATION OF CROSS SECTION A-A', SEE FIGURE 2-15

REFERENCES:

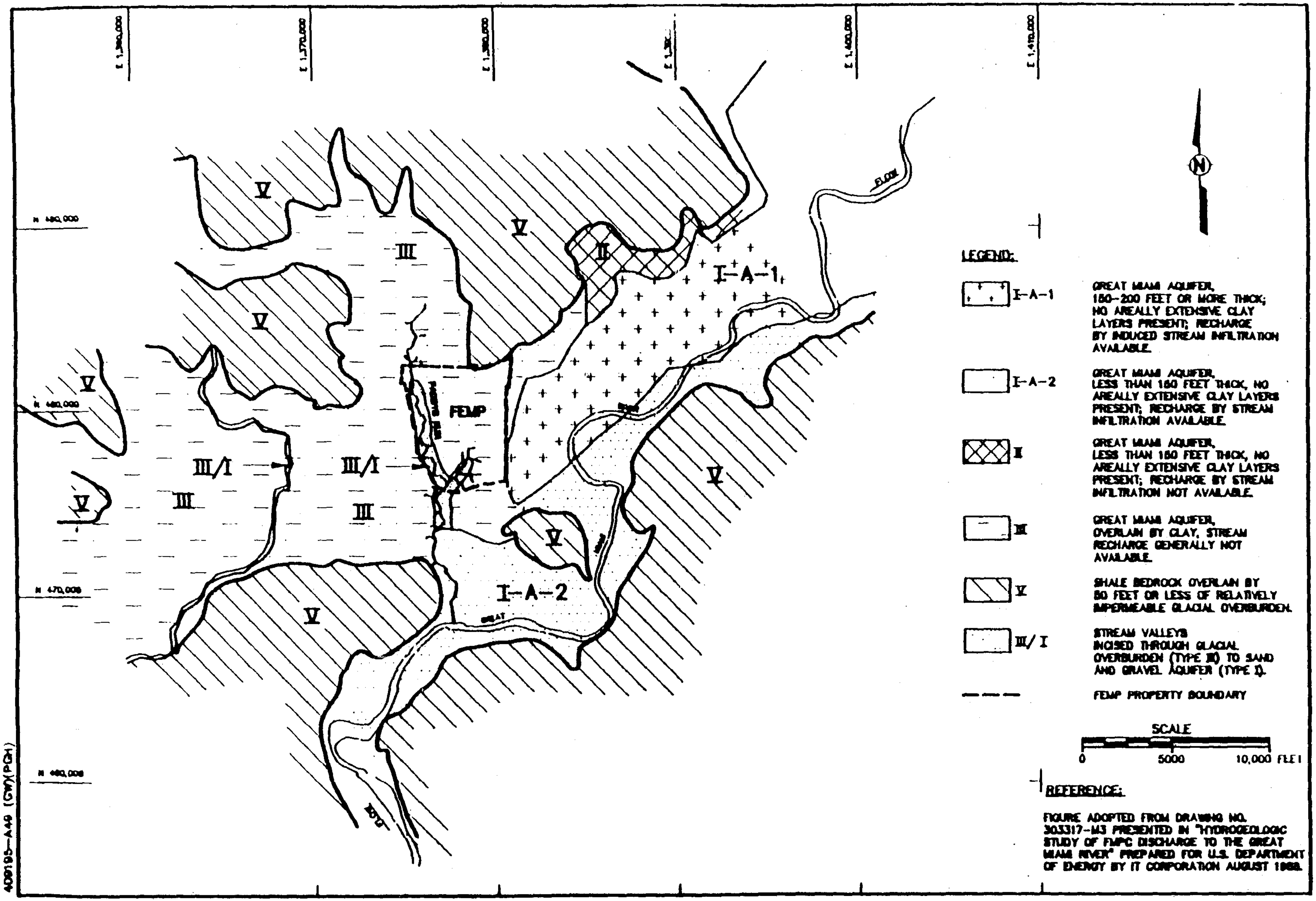
MODIFIED FROM U.S.G.S. PROFESSIONAL PAPER NO. 605-A USING AVAILABLE OHIO STATE WATER WELL RECORDS, SOWC WATER WELL DATA, DAMES & MOORE'S "FEED MATERIALS PRODUCTION CENTER GROUNDWATER STUDY, TASK C REPORT" FOR THE DOE (1985), AND IT (1986) RI/FS BORING LOGS.

FIGURE ADAPTED FROM FERNALD LITIGATION DRAWING NO. 303063-B18 PREPARED FOR U.S. DEPARTMENT OF ENERGY BY IT CORPORATION, NOVEMBER 1986.

408186-B22 (GW) (PCH)

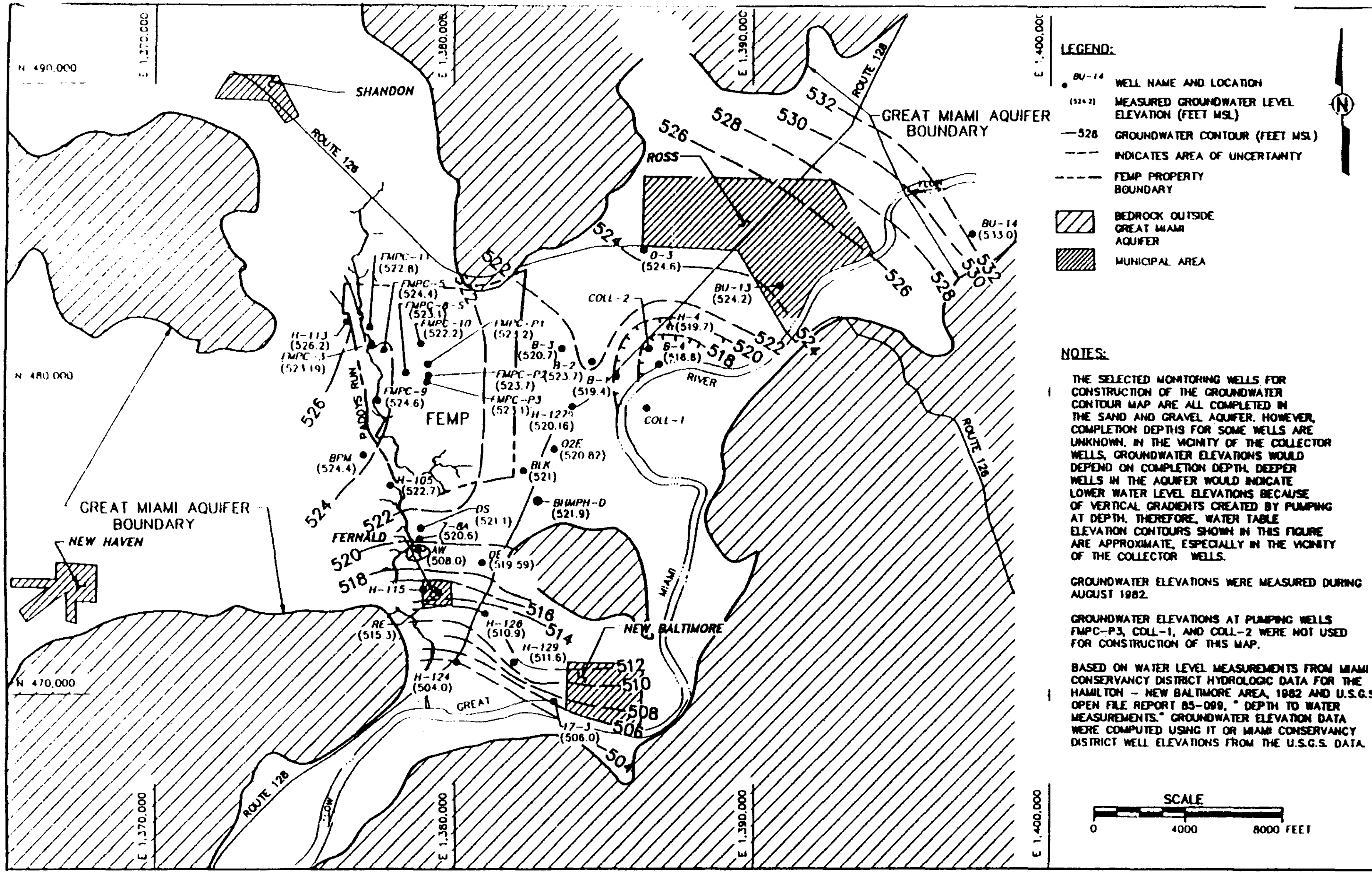
Fig. 2

GEOLOGIC CROSS SECTION A-A'
STUDY AREA



409195-A49 (GW)(PGH)

FIGURE 3 HYDROGEOLOGIC ENVIRONMENTS



REGIONAL GROUNDWATER ELEVATIONS
AUGUST 1982

Fig. 4

409195-838 (GW) (PGH)

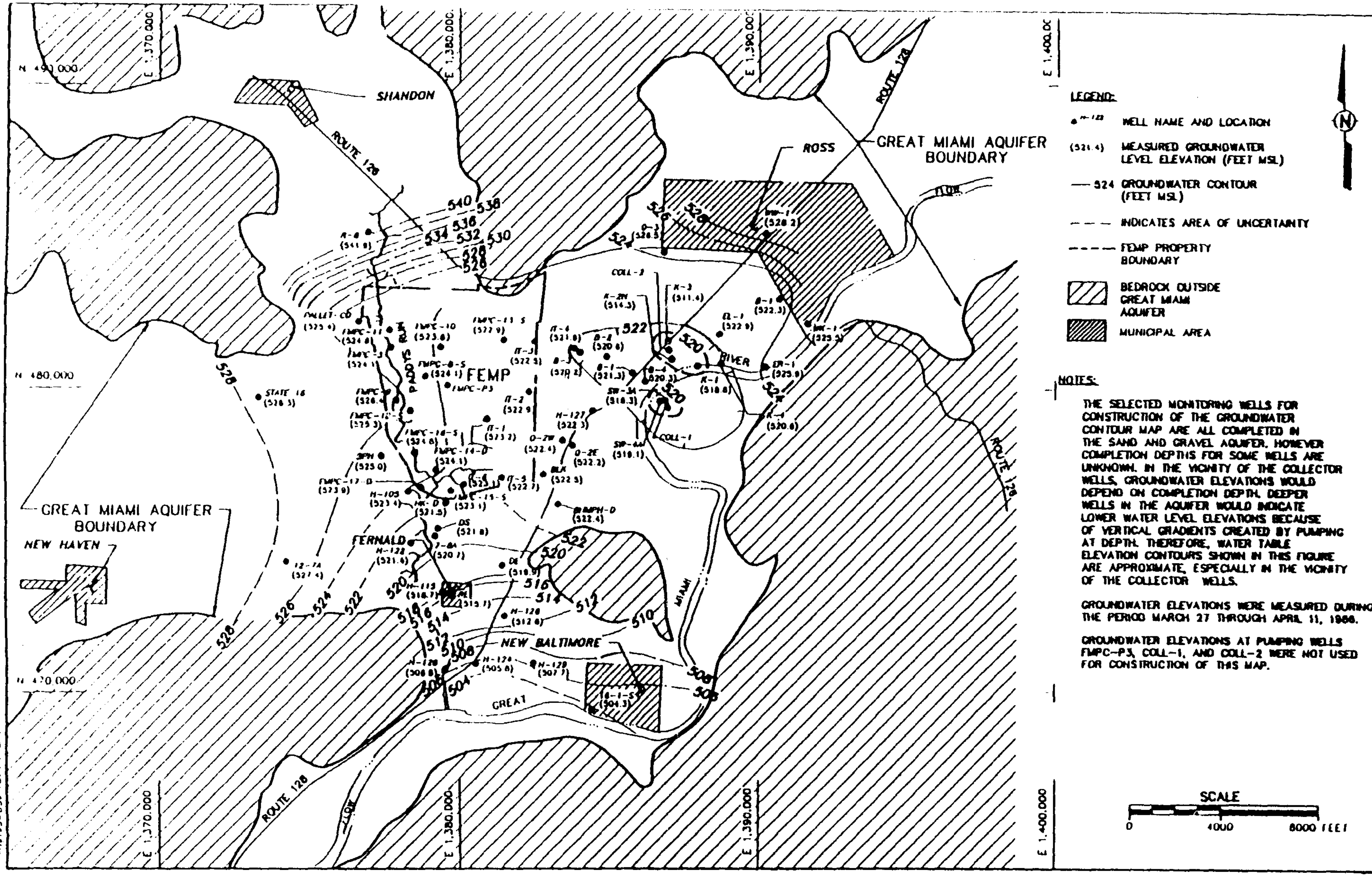


Fig. 5

REGIONAL GROUNDWATER ELEVATIONS
APRIL 1986

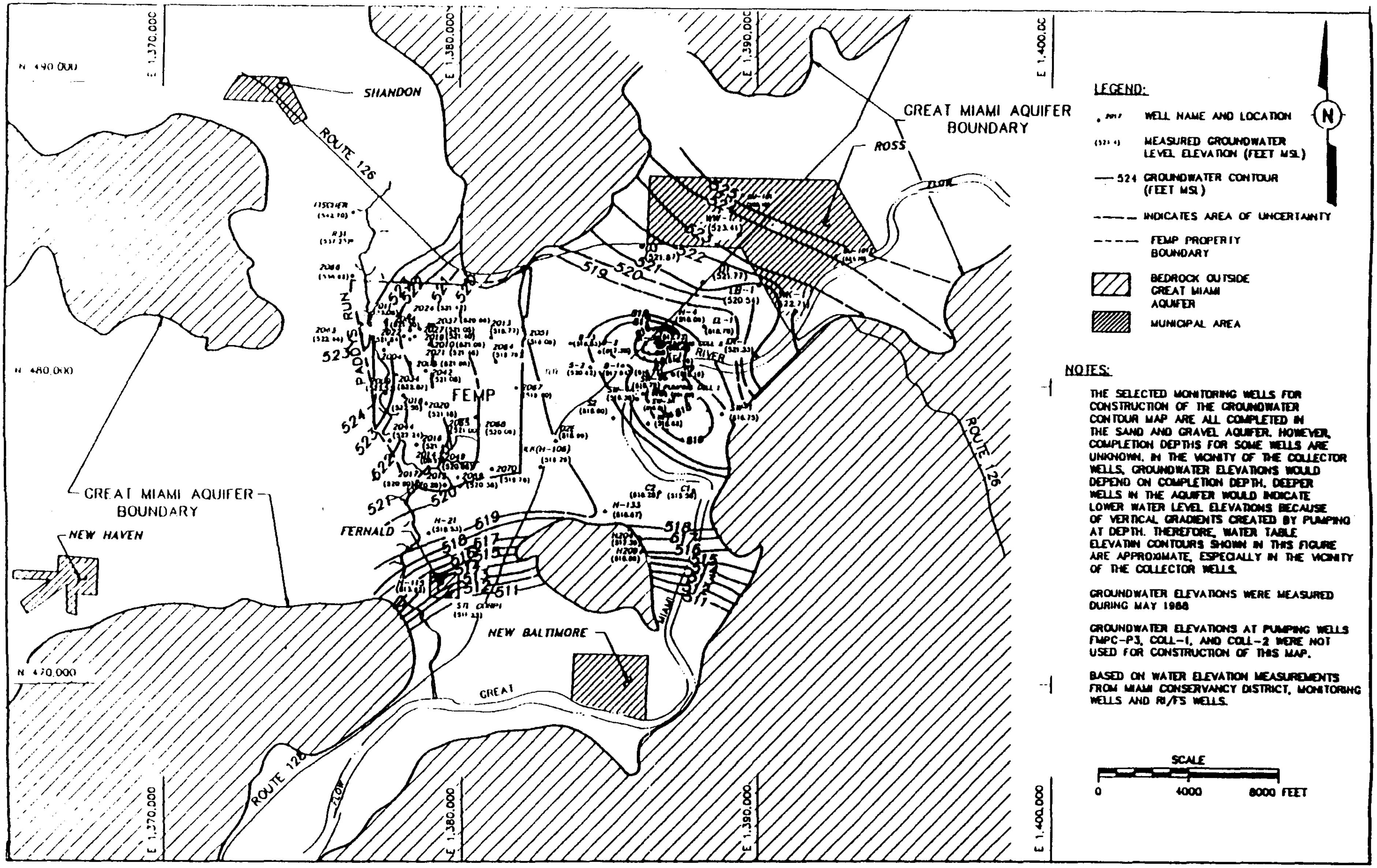


Fig. 6

REGIONAL GROUNDWATER ELEVATIONS
MAY 1988

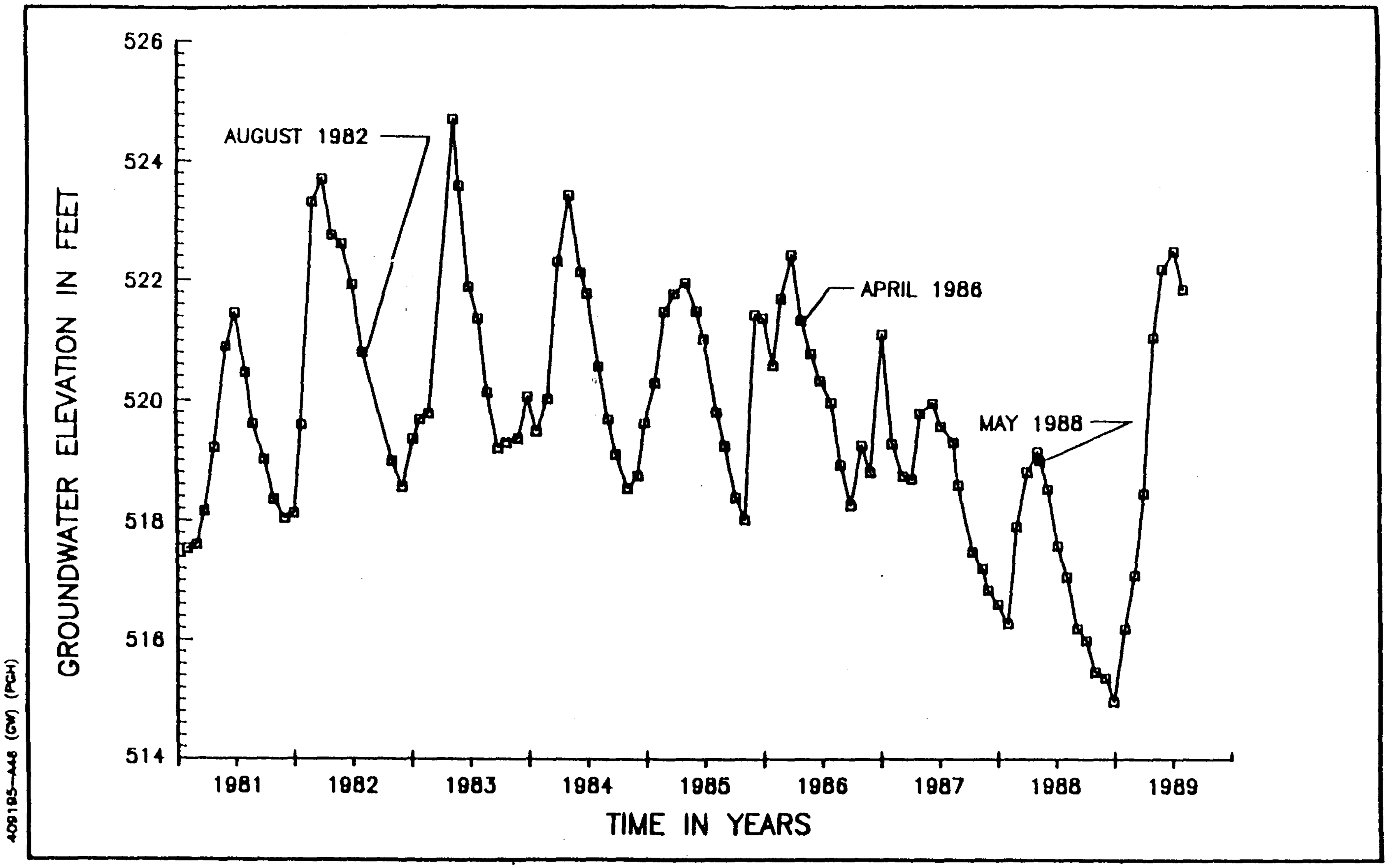


Fig. 7 HYDROGRAPH OF WELL O2E
JANUARY 1981 - DECEMBER 1989

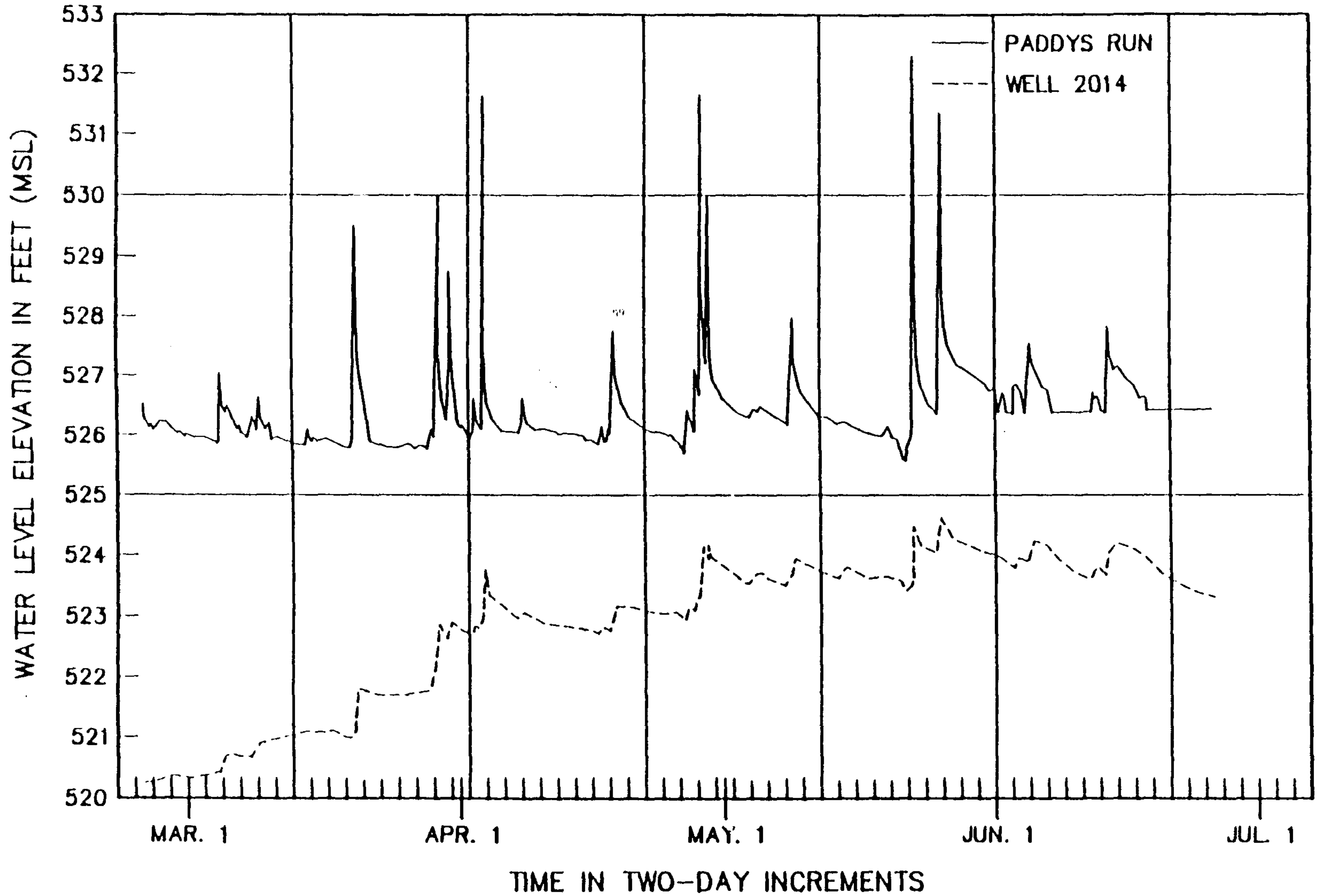


Fig. 8 HYDROGRAPH OF PADDYS RUN AND GREAT MIAMI AQUIFER AT WELL LOCATION 14, FEBUARY 24,1989 – JUNE 26, 1989

409195-A50 (GW) (PGH)

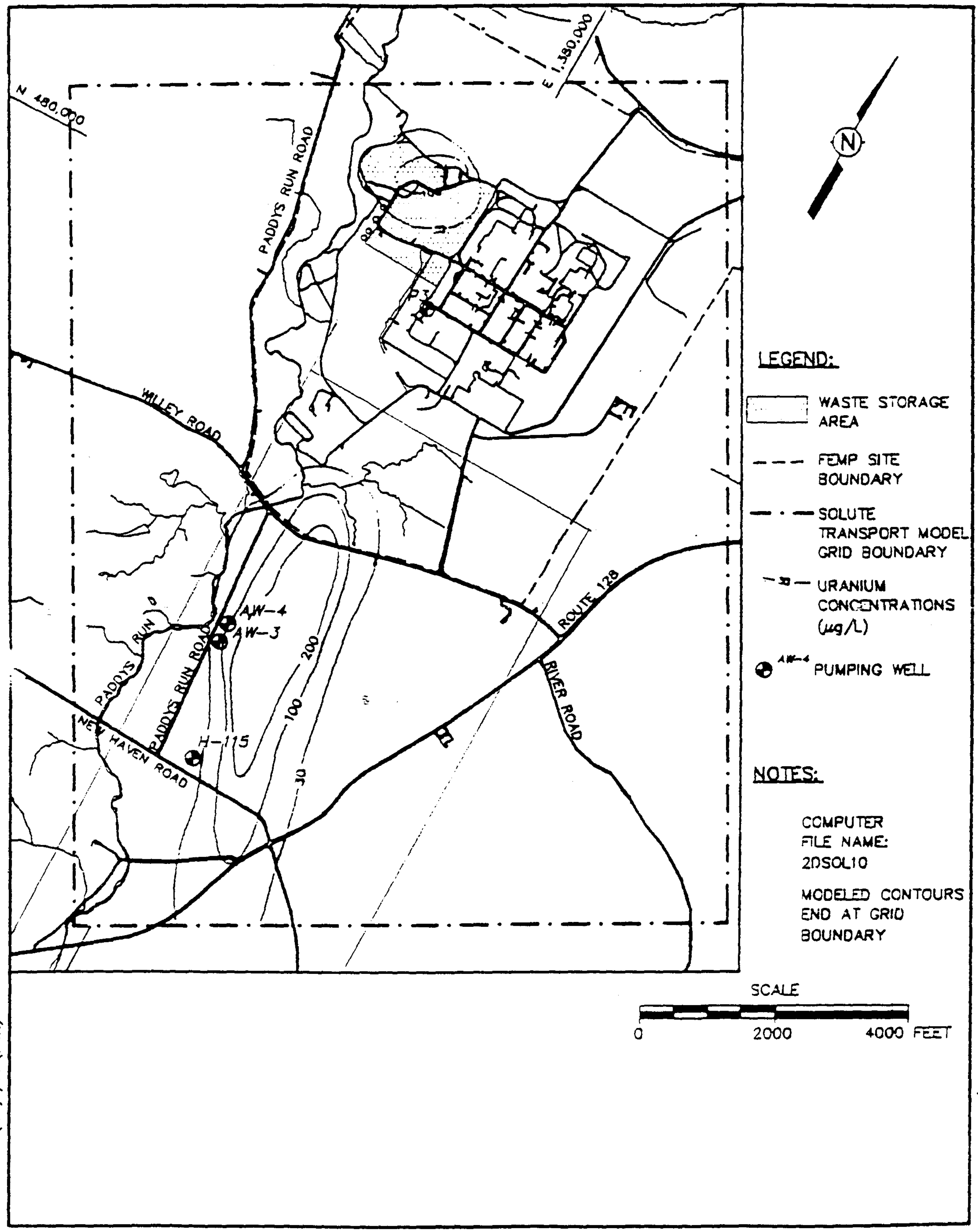
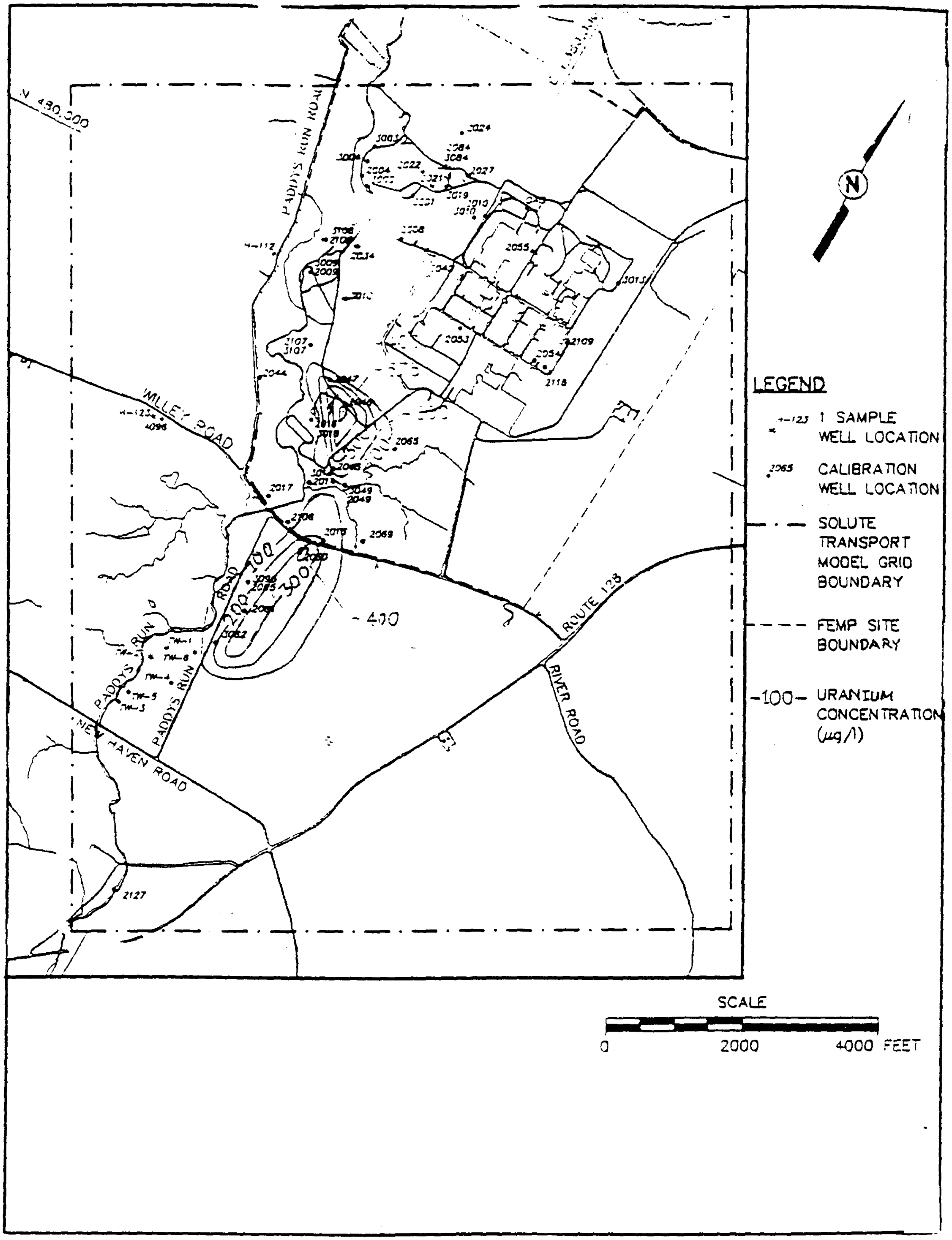


Fig. 9 2-DIMENSIONAL SOLUTE TRANSPORT MODEL
SIMULATED URANIUM CONCENTRATIONS
PRESENT CONDITIONS



409195-A54 (GW) (PGH)

Fig. 10 OBSERVED URANIUM CONCENTRATIONS
2000 SERIES WELLS